Nuclear Processes due to the Interaction of the Neutron with the Electron

Any sort of short range interaction between the neutron and the electron[1] will give rise to following processes, when the neutrons will pass through matter.

a) Processes which are independent of the internal structure of the nucleus.

i) Inelastic scattering by the free electron. Condon[2] found the cross section to have the order of magnitude

$$\sigma \sim \varkappa^2 \times 10^{-32} \mathrm{cm}^2,$$

assuming the potential energy to have a value $\varkappa mc^2$ for the distance smaller than e^2/mc^2.

ii) Inelastic scattering of the fast neutron with the emission of the electron from the K-level.

$$\sigma \sim \varkappa^2 \times \left(\frac{Z}{80}\right)^3 \times 10^{-33} \mathrm{cm}^2$$

iii) Inelastic scattering of the fast neutron with the creation of the pair of electrons. The cross section will have the same order of magnitude as that of ii). The ratio will be larger as Z and the neutreon energy increase.

iv) Elastic scattering of the slow neutron by orbital electrons. According

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1) One type of interaction was suggested by Gamow and Teller (Phys. Rev. **51**, 289, 1937) as an extension of the β-transformation theory.

2) Condon, Phys. Rev. **49**, 459, 1936.

to Condon,[2] the restriction $\kappa < 30$ is necessary in order to account for the experimental results. This makes the occurrence of all the processes i), ii) and iii) too rare to be observable.

b) Proper nuclear processes.

i) Emission of the electron from the K-level at the same time with the ~~transito~~ transition of the nucleus excited by the fast neutron. This process can not be distinguished from the ordinary internal conversion. The relative importance will depend on the magnitude of κ as well as the structure of the nucleus concerned.

ii) Emission of the pair by the similar nuclear transition. This also can not be distinguished from the internal pair creation.

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April 17, 1937.

Points ~~from the Recent Investigation~~

g 10^{-42} Z 10^{-30}

1\. ~~On the Interaction of Elementary Particles~~
(~~A Consistent Theory of the Nuclear Force and the β-Disintegration~~)

In order to account for the instantaneous emission of electrons by collision of neutrons with ~~matter~~ various substances, we can consider ~~an electron~~ the ~~interaction~~ fast direct ~~the~~ interaction between them ~~of the heavy and the light particles~~ ~~This~~ Such an interaction results in ~~K-electron~~ ~~be~~ the following processes

i) Inelastic Scattering of Neutrons by free electron

ii) ~~Absorption of Neut~~ Inelastic Scattering of Neutrons ~~by atoms~~ with the ~~ionization~~ emission of the electron from K-levels

iii) Inelastic ~~Scattering~~ of neutrons with the creation of ~~the the~~ pair of electrons

If we assume the interaction ~~has~~ potential has an appreciable value κmc^2 only when their mutual distance is ~~the order~~ of smaller than $\frac{e^2}{mc^2}$, the cross sections of these processes has the ~~values~~ order of magnitude per atom

$$\text{i)} \quad \sigma \cong \kappa^2 \times 1.24 \times 10^{-32}\,\text{cm}^2 \times Z$$

$$\text{ii)} \quad \sigma \cong \kappa^2 \times \left(\frac{Z}{80}\right)^3 \times 10^{-33}\,\text{cm}^2,$$

so that ~~(iii)~~ κ ~~will be~~ should ~~be~~ have the order of magnitude $10^2 \sim 10^3$ in order to have a value

$$\sigma \cong 10^{-25}\,\text{cm}^2$$

1936
(Phys. Rev. 49 March 15)

On the other hand, according to Condon, κ should be smaller than ~~32~~ 30 in order to be in accord with the scattering cross of various atoms for slow neutrons.

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Condon, ~~Note~~ Phys. Rev. 49, 459, 1936.

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On the Interaction of Neutrons with Electrons

i) electron $\psi_k = \frac{1}{\sqrt{\pi a^3}} e^{-\frac{r}{a}}$ $a = \frac{a_0}{Z}$ ~~$a_0 = \frac{\hbar c Z}{\alpha}$~~

a) initial state $a_0 = \frac{\hbar^2}{me^2} = \frac{e^2}{mc^2} \times (137)^2$

b) final state $\psi_f =$ ~~[illegible]~~ $e^{\frac{ipr}{\hbar}}$

ii) neutron $K\delta(r-R)$

$u = e^{\frac{iP_0R}{\hbar}}$

$v = e^{\frac{iPR}{\hbar}}$

$$\frac{MW}{P_0} \frac{4\pi^2 K^2}{h} \cdot \left|\iint e^{+\frac{i}{\hbar}(P_0-P)R} e^{-\frac{ipr}{\hbar}} \frac{1}{\sqrt{\pi a^3}} e^{-\frac{r}{a}} \delta(r-R)\right|^2$$

statistical weight: $W_n = \frac{4\pi P^2 dP}{h^3 dE} = \frac{4\pi P M}{h^3}$,

$E = \frac{P^2}{2M}$ $dE = \frac{2PdP}{M}$

$$\frac{16\pi^3 K^2}{h^4} \cdot \frac{P}{P_0}$$

$W_e =$ ~~pdp~~ $\frac{4\pi p m}{h^3}$

$\int d\Omega \int_0^\infty e^{-ik'r}$ ~~[illegible]~~ $e^{ikr} \cdot dr = 1.$

$W = \frac{(4\pi)^2}{h^6} p P m M.$

$E' = $ ~~[illegible]~~ $\frac{(\hbar k)^2}{2m}.$

$dE' = \frac{h^2 k^2}{8\pi^2 m}.$

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$$\frac{1}{L^3}\cdot\frac{T^7\;M^3\;M^2L^4}{M^7L^{14}\cdot T^4}\times L^6 \;\frac{ML}{T}\cdot\frac{ML^2}{T^2} =$$

$$\frac{1}{\pi a^3}\cdot\frac{mM^2(4\pi)^4K^2\cdot p}{\hbar^7\cdot\;\;p_0}\left|\int e^{\frac{i\vec r}{\hbar}(\vec p_0-\vec p_0'-\vec p)}e^{-\frac{r}{a}}d\vec r\right|^2$$

pdE

$=$

$$\frac{\vec r(\vec p_0-\vec P-\vec p)}{\hbar} = r\vec q\cos\theta$$

$$\int_0^\infty e^{(\frac{iq}{\hbar}-\frac{1}{a})r}r^2dr =$$

$$\int e^{irq\cos\theta}\sin\theta d\theta = \frac{e^{irq}-e^{-irq}}{irq}$$

$$|\quad| = \frac{1}{q^2}\left|\,\mathrm{Im}\int_0^\infty e^{ir(q-\frac{1}{a})}r\,dr\right|^2$$

$$\left|\frac{1}{i(q-\frac{1}{a})}e^{ir(q-\frac{1}{a})}r\Big|_0^\infty-\int_0^\infty\frac{e^{ir(q-\frac{1}{a})}}{i(q-\frac{1}{a})}dr\right|$$

$$=\frac{1}{(q-\frac{1}{a})^2}\qquad \frac{1}{q^2(q-\frac{1}{a})^4}\longrightarrow\frac{a^4}{q^2}$$

$$K=\left(\frac{e^2}{mc^2}\right)^3\cdot mc^2$$

$$\frac{M^2m^4e^5}{m^6c^8}$$

$$\kappa^2\cdot\frac{(4\pi)^4}{\pi}\cdot\frac{mM^2}{\hbar^7}\left(\frac{e^2}{mc^2}\right)^6(mc)^2\frac{mc\cdot mc^2\cdot\hbar^6}{a^3(mc)^4(mc)^6}$$

$$\frac{M^2m^4c^5\hbar^6}{\hbar^7\cdot m^7c^{10}}$$

$$=\kappa^2\cdot\frac{(4\pi)^4}{(4\pi)^3\pi}\frac{M^2}{\hbar^3\cdot e\,m^2c^3a^3}\frac{M^2\cdot e^4}{\hbar\cdot m^3c^4}=\frac{\kappa^2}{4^3\pi^4a^3}\left(\frac{e^2}{\hbar c}\right)^2\frac{\hbar}{mc^2}\left(\frac{M}{m}\right)^3$$

$\frac{\hbar^3}{m} \left(\frac{\hbar c}{e^2}\right)^4$

$\kappa^2 \cdot \frac{1}{(4\pi)^3\pi} \cdot \frac{M^2}{\hbar} \cdot \left(\frac{e^2}{mc^2}\right)^6 \cdot \frac{(mc^2)^4}{a^3 c (mc)^6} \times \left(\frac{mc}{\hbar}a\right)^4$

$= \kappa^2 \cdot \frac{1}{(4\pi)^3\pi} \frac{M^2}{\hbar} \left(\frac{e^2}{mc^2}\right)^6 \frac{1}{m^3} \cdot \left(\frac{me}{\hbar^2}\right)^3 \left(\frac{me^2}{\hbar^2}\right)^3 \cdot Z^3 \times \left(\frac{\hbar c}{e^2}\right)^6$

$= \kappa^2 \cdot \frac{1}{(4\pi)^3\pi} \left(\frac{M}{m}\right)^2 \left(\frac{e^2}{\hbar c}\right)^9 \cdot \frac{\frac{\hbar}{me}}{\left(\frac{\hbar^2}{m^2c^2}\right)} Z^3$

$= \kappa^2 \frac{1}{(4\pi)^3\pi} \left(\frac{M}{m}\right)^2 \cdot \left(\frac{e^2}{\hbar c}\right)^3 \cdot \left(\frac{e^2}{mc^2}\right)^2 Z^3.$

$= \kappa^2 \frac{1}{64 \times 100} 1840^2 \times \left(\frac{1}{137}\right)^3 \times Z^3 \times (2.8)^2 \times 10^{-26}$

$\kappa^2 \frac{3.4 \times 10^5}{6.4 \times 10^3} \times \frac{Z^3 \times 7.84 \times 10^{-26}}{2.5 \times 10^6 \quad 9 \times 10^{14}} = \kappa^2 \times \frac{3.4 \times 7.84}{6.4 \times 2.5} \times 10^{-30} Z^3$

1840
1840
7360
1472
184
3385̇60

137 0.13672
3
0.95704
0.4
10^{12}

$Z = 80.$

64
8
500

$Z^3 = 5 \times 10^5$

2.8
2.8
224
56
7.84

$\kappa^2 \times \frac{3.4 \times 7.84 \times 5}{6.4 \times 9} \times 10^{-33} \simeq \kappa^2 \times 10^{-33}$

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$\gamma \to 1$

$$P_K = \frac{4\pi m(\alpha Z)^3}{\{\Gamma(3)\}^3 \hbar^3} \cdot \left(\frac{4\pi mc}{\hbar}\right)^4 R_p^2 \, \eta \sqrt{\varepsilon'^2 - 1}$$

$$e^{\pi\alpha Z \frac{\varepsilon'}{\eta'}} |\Gamma(1 + i\gamma\alpha Z \frac{\varepsilon'}{\eta'})|^2 (\varepsilon' + \gamma)$$

$\varepsilon' \simeq 1,$

$\varepsilon'^2 - 1 \simeq 1.$ etc

$e^{\pi\alpha Z \frac{\varepsilon'}{\eta'}} \simeq 1.$ etc

$$P_K = \frac{m(\alpha Z)^3}{\pi^2 \hbar^3} \cdot \left(\frac{mc}{\hbar}\right)^4 \cdot R_p^2 \quad = [T^{-2}]$$

$$R_p \cong \int V_0(\vec{R}) e^{\frac{i(\vec{p}_0 - \vec{p})\vec{R}}{\hbar}} d\vec{R}$$

$$e^2 R_p^2 = e^2 \times$$

$$R_p^2 = ML^2T^{-2} \times L^2$$

$$\frac{m(\alpha Z)^3}{\pi^2 \hbar^3} \left(\frac{mc}{\hbar}\right)^4 =$$